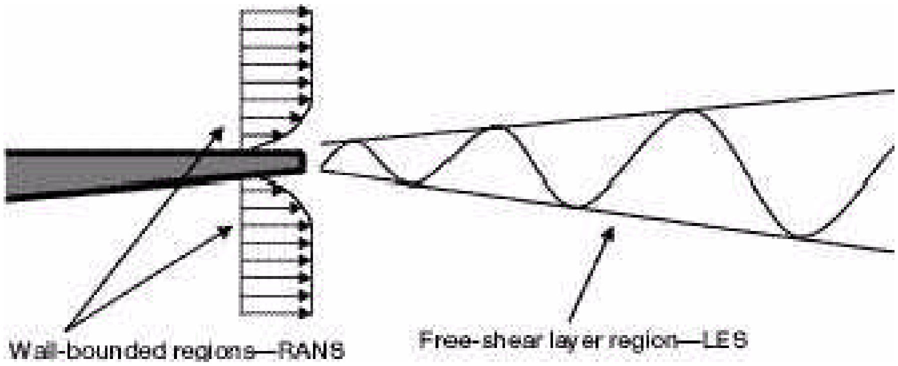
Development of a Hybrid RANS/LES Method for Turbulent Mixing Layers

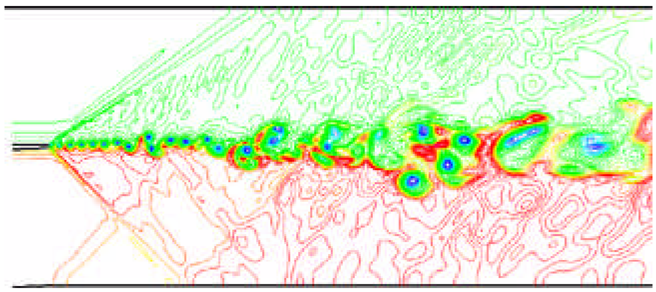
Significant research has been underway for several years in NASA Glenn Research Center's nozzle branch to develop advanced computational methods for simulating turbulent flows in exhaust nozzles. The primary efforts of this research have concentrated on improving our ability to calculate the turbulent mixing layers that dominate flows both in the exhaust systems of modern-day aircraft and in those of hypersonic vehicles under development. As part of these efforts, a hybrid numerical method was recently developed to simulate such turbulent mixing layers. The method developed here is intended for configurations in which a dominant structural feature provides an unsteady mechanism to drive the turbulent development in the mixing layer.

Interest in Large Eddy Simulation (LES) methods have increased in recent years, but applying an LES method to calculate the wide range of turbulent scales from small eddies in the wall-bounded regions to large eddies in the mixing region is not yet possible with current computers. As a result, the hybrid method developed here uses a Reynolds-averaged Navier-Stokes (RANS) procedure to calculate wall-bounded regions entering a mixing section and uses a LES procedure to calculate the mixing-dominated regions. A numerical technique was developed to enable the use of the hybrid RANS-LES method on stretched, non-Cartesian grids. With this technique, closure for the RANS equations is obtained by using the Cebeci-Smith algebraic turbulence model in conjunction with the wall-function approach of Ota and Goldberg. The LES equations are closed using the Smagorinsky subgrid scale model. Although the function of the Cebeci-Smith model to replace all of the turbulent stresses is quite different from that of the Smagorinsky subgrid model, which only replaces the small subgrid turbulent stresses, both are eddy viscosity models and both are derived at least in part from mixing-length theory. The similar formulation of these two models enables the RANS and LES equations to be solved with a single solution scheme and computational grid.

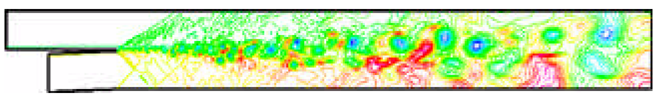
The hybrid RANS-LES method has been applied to a benchmark compressible mixing layer experiment in which two isolated supersonic streams, separated by a splitter plate, provide the flows to a constant-area mixing section. Although the configuration is largely two dimensional in nature, three-dimensional calculations were found to be necessary to enable disturbances to develop in three spatial directions and to transition to turbulence. The flow in the initial part of the mixing section consists of a periodic vortex shedding downstream of the splitter plate trailing edge. This organized vortex shedding then rapidly transitions to a turbulent structure, which is very similar to the flow development observed in the experiments. Although the qualitative nature of the large-scale turbulent development in the entire mixing section is captured well by the LES part of the current hybrid method, further efforts are planned to directly calculate a greater portion of the turbulence spectrum and to limit the subgrid scale modeling to only the very small scales. This will be accomplished by the use of higher accuracy solution schemes and more powerful computers, measured both in speed and memory capabilities.



Mixing layer illustrating the hybrid RANS-LES approach.



Instantaneous density contours for the entire mixing section.



Instantaneous density contours near the beginning of the mixing section.

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